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Reflect array in K and Ka Bands with Independent Beams in Each Polarization

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Abstract: This contribution describes the design of a printed reflectarray antenna to operate at 19.7 and 29.5 GHz with independent beams in H and V polarizations. A dual-frequency dual-polarization reflectarray cell, made of two stacked sets of parallel dipoles for each polarization, is proposed. The dipole lengths are adjusted to produce the required phase-shift at each frequency and each polarization. A 1.6-m reflectarray has been designed to produce two closely spaced beams in H and V polarizations. The simulated radiation patterns show a gain of 48.3 dBi at 19.7 GHz and 50.7 dBi at 29.5 GHz, with side-lobe levels close to -25 dB and low cross-polar radiation.

Keywords*:* Reflect array, dual polarization, dual frequency, parallel dipoles, Ka-band antennas, satellite antennas.

References:

[1] J. Huang and J. A. Encinar, “Reflectarray Antennas”, IEEE Press/Wiley, Piscataway, New Jersey, 2008.

[2] H. Hasani, C. Peixeiro, A. Skrivervik, J. Perruisseau-Carrier, "Single-Layer Quad-Band Printed Reflectarray Antenna with Dual Linear Polarization," IEEE Trans. on Antennas and Propag., vol.63, no.12, pp. 5522-5528, Dec. 2015

[3] M. R. Chaharmir, J. Shaker, H. Legay, “Dual-band Ka/X reflectarray with broadband loop elements”, Microwaves, Antennas & Propagation, IET, vol. 4, no. 2, pp. 225-231, Feb. 2010.

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[5] R. Florencio, J. A. Encinar, R. R. Boix, V. Losada, G. Toso, "Reflectarray Antennas for Dual Polarization and Broadband Telecom Satellite Applications," IEEE Trans. on Antennas and Propag., vol. 63, pp. 1234-1246, April 2015.

Eduardo Martínez de Rioja was born in Madrid, Spain. He received the Telecommunications Engineering degree in 2014 from Universidad Politécnica de Madrid (UPM), Spain. In 2015, he joined the Applied Electromagnetics Group at UPM, where he is currently working toward the Ph. D. degree in Communications Systems and Technologies after being awarded a Research Scholarship from the Spanish Ministry of Economy. His research involves the design of dual-frequency multi-beam reflectarrays for space antennas in Ku and Ka Bands, with both single and dual-reflector configurations.

José A. Encinar was born in Madrid, Spain. He received the Electrical Engineer and Ph.D. degrees, both from Universidad Politécnica de Madrid (UPM), in 1979 and 1985, respectively.

Since January 1980, he has been with the Applied Electromagnetics Group at UPM, as a Teaching and Research Assistant from 1980 to 1982, as an Assistant Professor from 1983 to 1986, and as Associate Professor from 1986 to 1991. From February to October of 1987, he was a Postdoctoral Fellow of the NATO Science Program with the Polytechnic University, Brooklyn, NY, USA. Since 1991 he is a Professor of the Electromagnetism and Circuit Theory Group, currently in the Department of Signals, Systems and Radio Communications at UPM. He was a Visiting Professor with the Laboratory of Electromagnetics and Acoustics at Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland, in 1996, and with the Institute of Electronics, Communication and Information Technology (ECIT), Queen's University Belfast, U.K., in 2006 and 2011. His research interests include numerical techniques for the analysis of multi-layer periodic structures, design of frequency selective surfaces, printed arrays and reflectarrays.

Prof. Encinar has co-authored more than 200 journal and conference papers, one book and several book chapters. He is holder of five patents on array and reflectarray antennas. He was a co-recipient of the 2005 H. A. Wheeler Applications Prize Paper Award and the 2007 S. A. Schelkunoff Transactions Prize Paper Award, given by IEEE Antennas and Propagation Society. He has been a member of the Technical Programme Comity of several International Conferences (European Conference on Antennas and Propagation, ESA Antenna Workshops, Loughborough Antennas & Propagation Conference).

Rafael Florencio received the Licenciado degree in Physics from the University of Seville, Spain, in 2008, the Master and PhD degrees in "Communications Technology and Systems" from the Technical University of Madrid (UPM), Spain, in 2010 and 2016 respectively.
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Dr. Florencio was the recipient of a Scholarship financed by the Junta de Andalucía.

Rafael R. Boix received the Licenciado and Doctor degrees in Physics from the University of Seville, Spain, in 1985 and 1990 respectively.
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Reflectarray in *K* and *Ka* Bands with Independent Beams in Each Polarization

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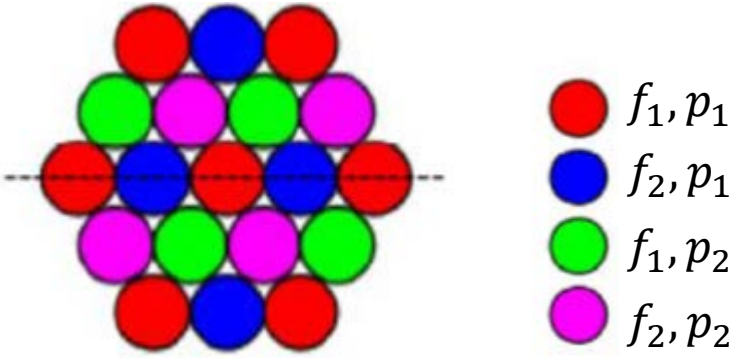
OUTLINE

- Introduction and objectives
- Dual-polarization dual-frequency reflectarray cell
- Design of a K and Ka band reflectarray
- Simulation results
- Conclusions

INTRODUCTION

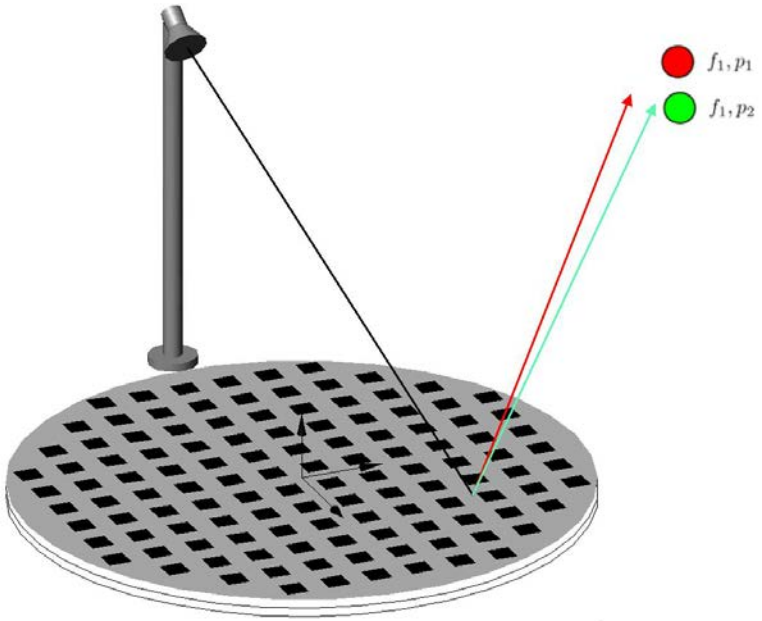
- Reflectarray antennas provide high values of gain, radiation efficiency, independent beams for each polarization, etc. Bandwidth is the most severe limitation.
- In the last years, reflectarrays have been also proposed for multi-frequency operation, using a single layer or stacked layers.
- Application to multi-spot beam satellite antennas in Ka-band, with frequency and polarization reuse: conventional reflectors cannot provide closely spaced beams, and 4 antennas are used.



OBJECTIVES

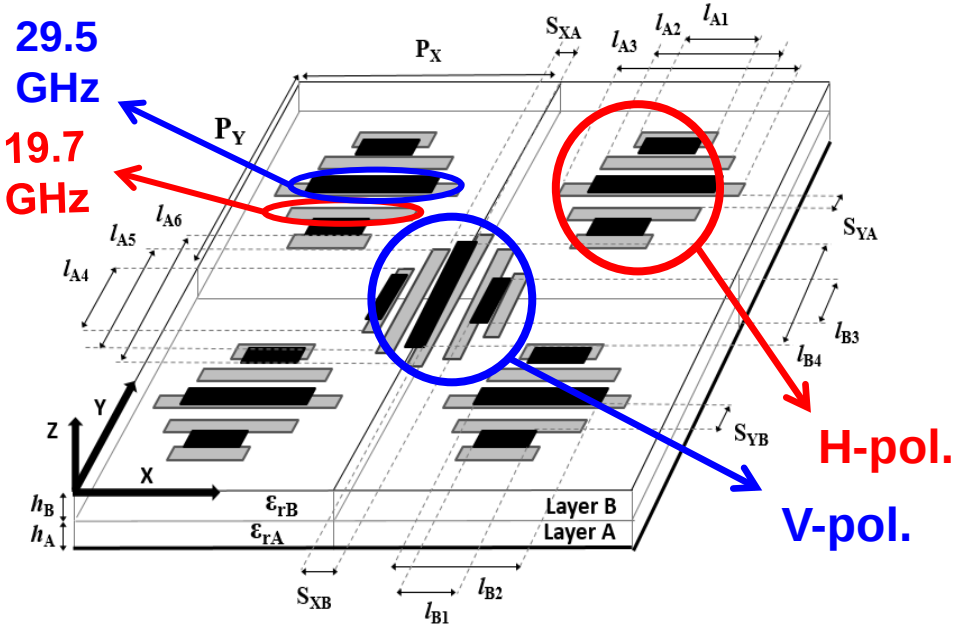
- Using reflectarrays, each feed can generate 2 beams discriminating in polarization (p1, p2) and/or 2 beams discriminating in frequency (f1, f2).

- Objectives:
  - To design a dual-frequency dual-polarization reflectarray cell.
  - To design a reflectarray antenna demonstrator with independent beams in K (20 GHz, Tx) and Ka (30 GHz, Rx) bands .
- Advantages:
  - Reduction in the number of antennas.
  - Low-cost and ease of integration.



REFLECTARRAY ELEMENT

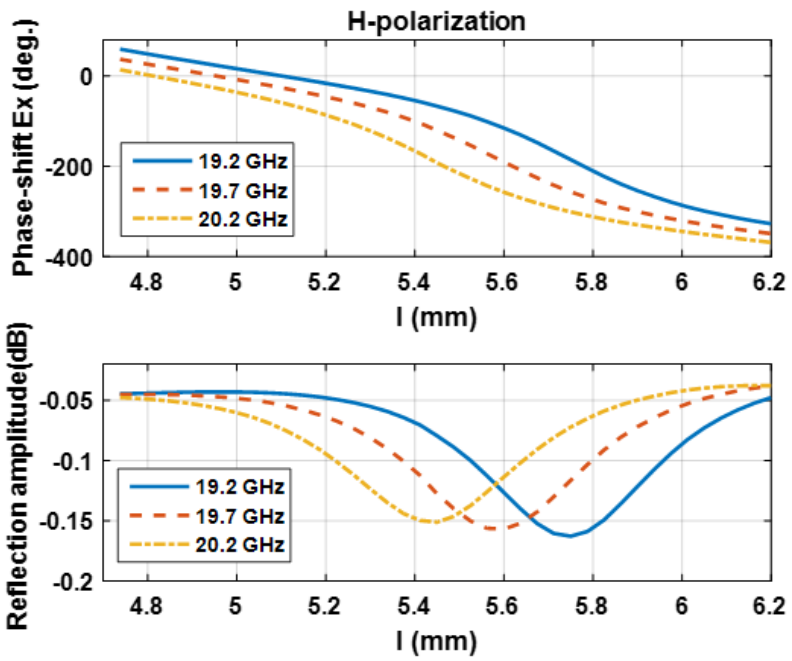
- Two-layer reflectarray cell, with two orthogonal sets of parallel dipoles.
- There are 8 dipoles for each linear polarization (5+3).
- The period is $P_x = P_y = 6.5$ mm ($0.67 \cdot \lambda$ at 30 GHz) to avoid the appearance of grating lobes.
- Dielectric layers:
  - Layer A: $h_A = 1.5$ mm, $\varepsilon_r = 2.17$, $\tan\delta = 0.002$.
  - Layer B: $h_B = 1$ mm, $\varepsilon_r = 2.17$, $\tan\delta = 0.002$.

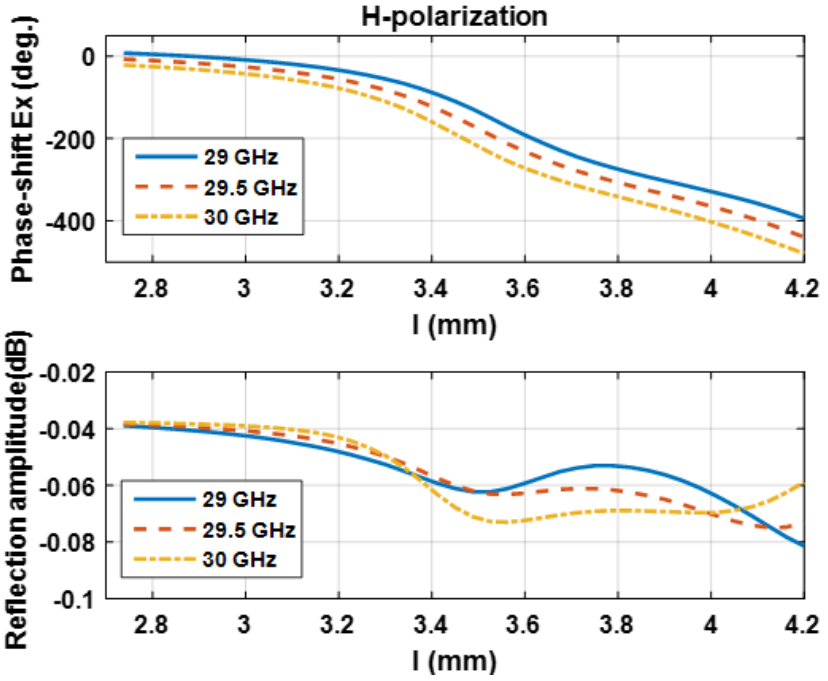


$$l_{A1} = 0.65 \cdot l_{A3},\ l_{A2} = 0.8 \cdot l_{A3},$$
$$l_{A4} = 0.65 \cdot l_{A6},\ l_{A5} = 0.8 \cdot l_{A6}$$
$$l_{B1} = 0.8 \cdot l_{B2},\ l_{B3} = 0.8 \cdot l_{B4}$$
$$S_{XA} = S_{YA} = 0.5 \text{ mm},\ S_{XB} = S_{YB} = 1 \text{ mm}$$
$$w = 0.25 \text{ mm}$$

PHASE RESPONSE (I)

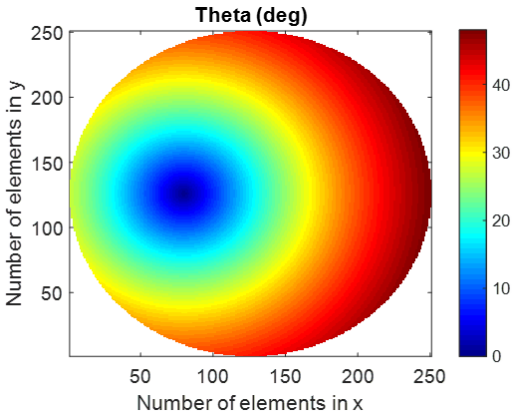
- Objectives: smooth response and wide phase range (>360º).
- Amplitude and phase curves calculated respect to the central dipole length, for each polarization and frequency band.
- Variations with angle of incidence, lengths of parallel dipoles on contiguous layer, etc. Orthogonal dipoles are practically uncoupled.



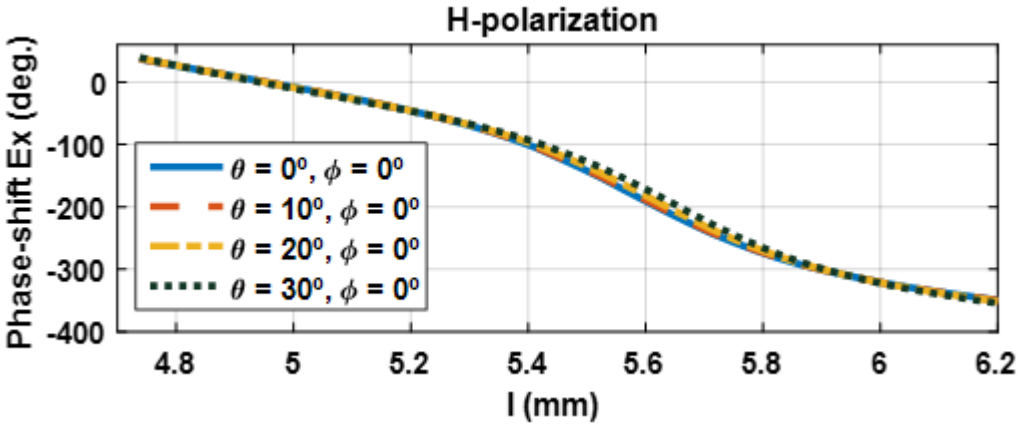


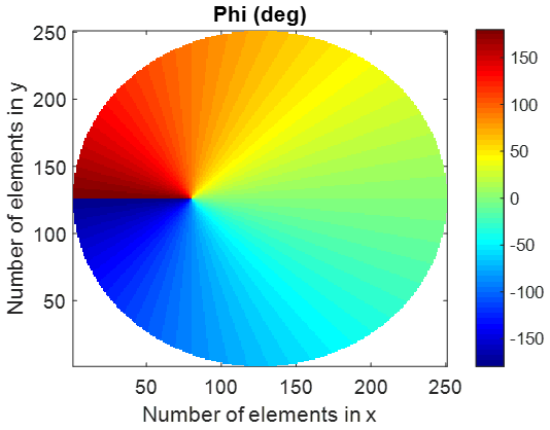
PHASE RESPONSE (II)

- Slight variations with the angle of incidence at TX & RX frequencies.

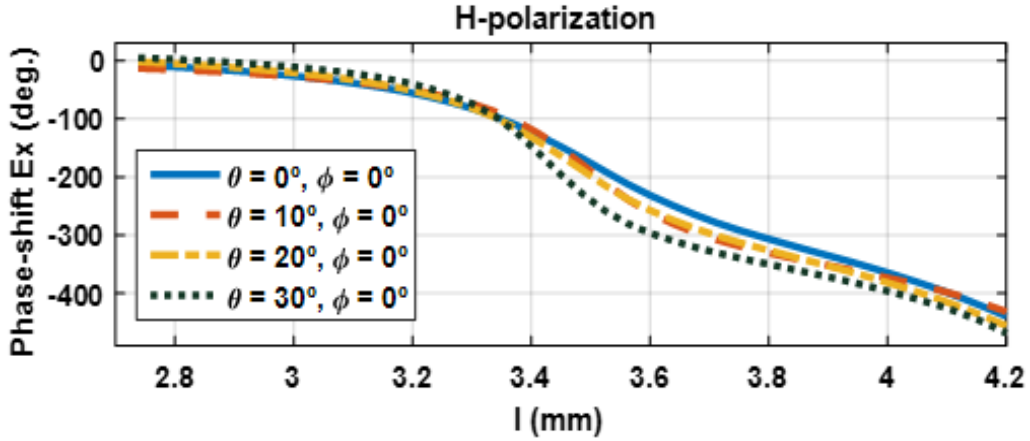


19.7 GHz





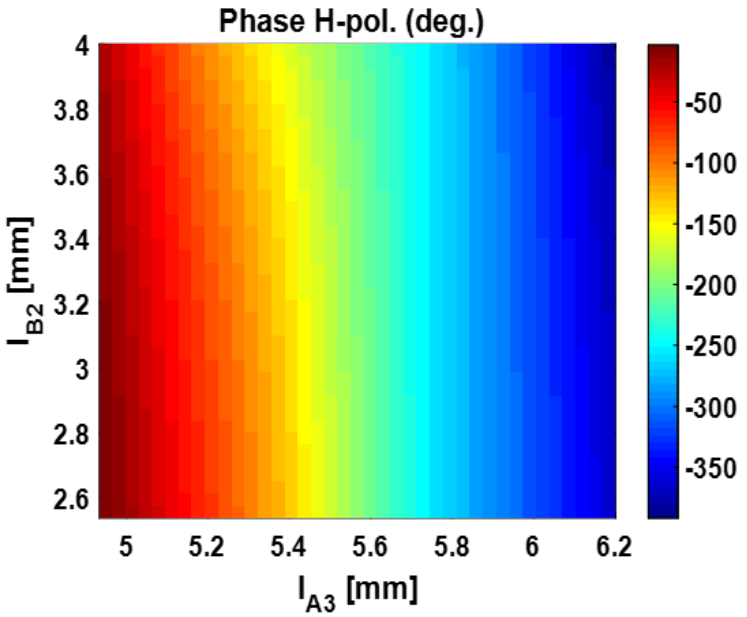
29.5 GHz



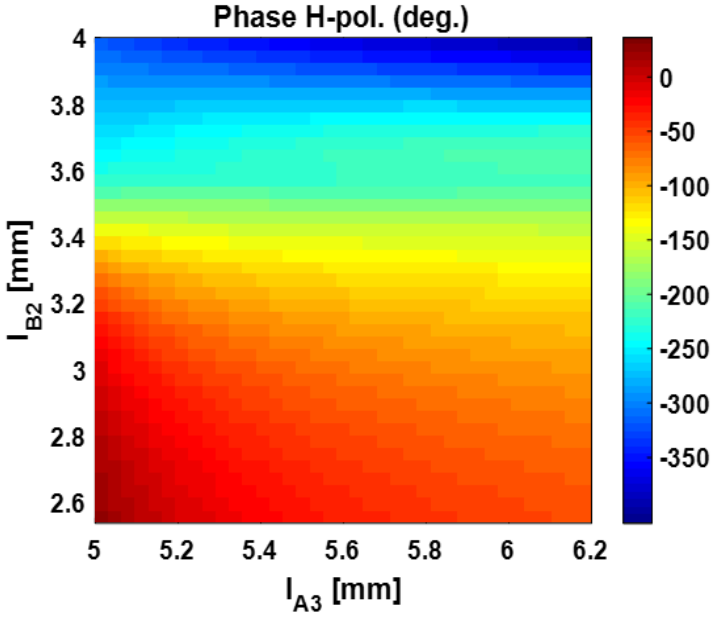
PHASE RESPONSE (III)

- Variations due to parallel dipoles on contiguous layers.
- Design of layer A at 19.7 GHz can be done independently from layer B, but this is not exactly true for layer B at 29.5 GHz respect to layer A.
- Improvement: multi-frequency optimization, once the design is completed, for each frequency band.

Phase variation at 19.7 GHz

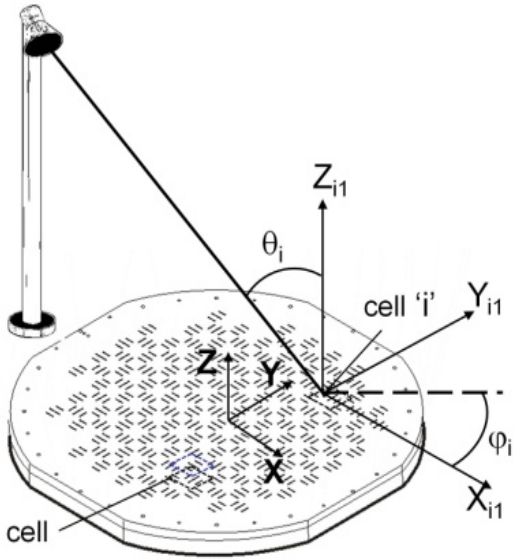


Phase variation at 29.5 GHz



DEMONSTRATOR DEFINITION

- Demonstrator size: 162.5-cm diameter circular reflectarray to provide >47 dBi gain at both frequency bands.
- Cell period: 6.5 x 6.5 mm, to avoid the appearance of grating lobes for angles up to 35º.
- The beam radiates with 10º respect to Z-axis for H polarization, and 10.5º for V polarization, at both design frequencies.
- The feed-horn is placed at coordinates (-30, 0, 100) cm, and the radiated field is modeled by $\cos^q(\theta)$ function, with q= 6 at 20 GHz, and q= 8 at 30 GHz.
- The edge illumination level is around -16 dB at 19.7 GHz, and -18 dB at 29.5 GHz.



Beam pointing direction:

H-pol: $\theta_b = 10º$, $\varphi_b = 0º$

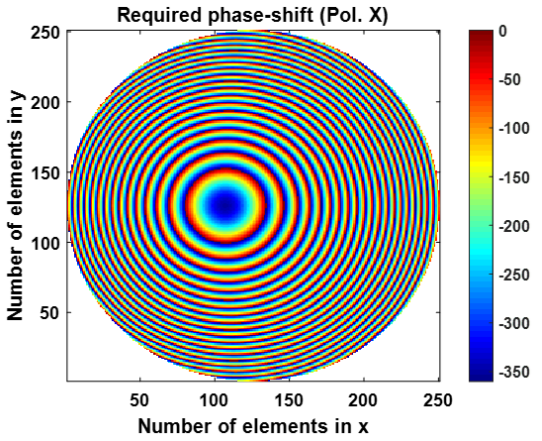
V-pol: $\theta_b = 10.5º$, $\varphi_b = 0º$

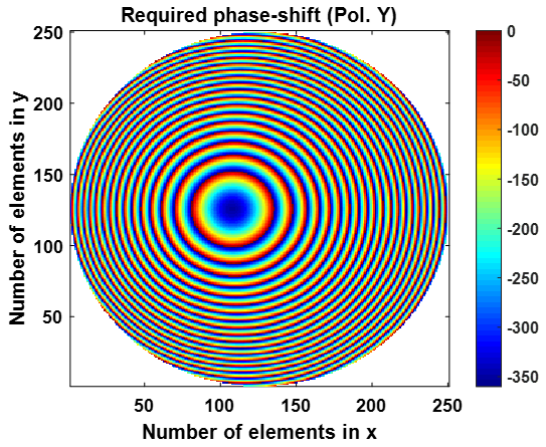
PHASE DISTRIBUTIONS

- Required phase-shift distributions are obtained for each polarization and frequency to generate the beams in the specified directions.

19.7 GHz H-pol.

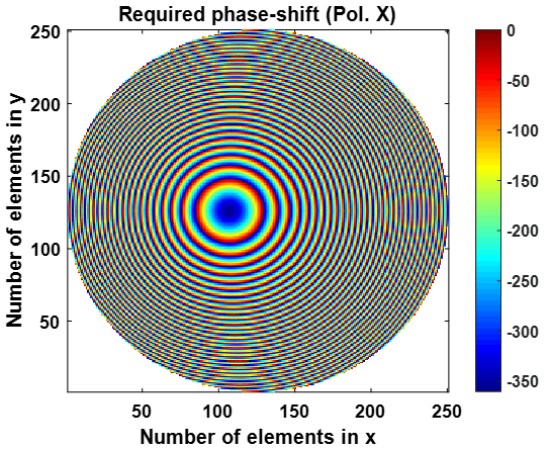
$\theta_b = 10^o$
$\varphi_b = 0^o$

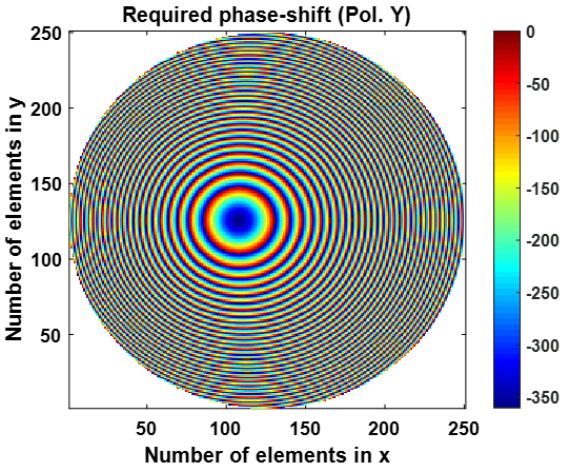




19.7 GHz V-pol.

29.5 GHz H-pol.



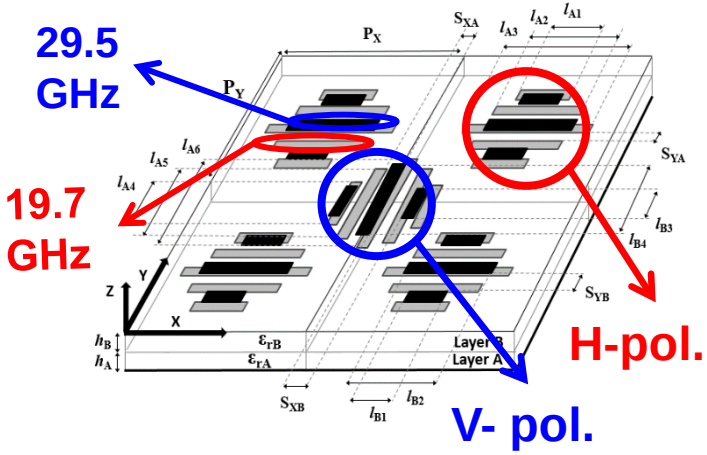


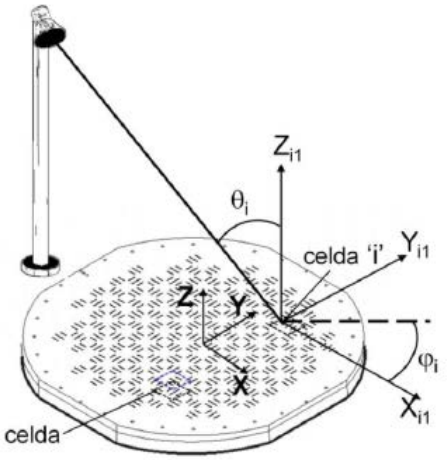
$\theta_b = 10.5^o$
$\varphi_b = 0^o$

29.5 GHz V-pol.

DUAL FREQUENCY DESIGN (I)

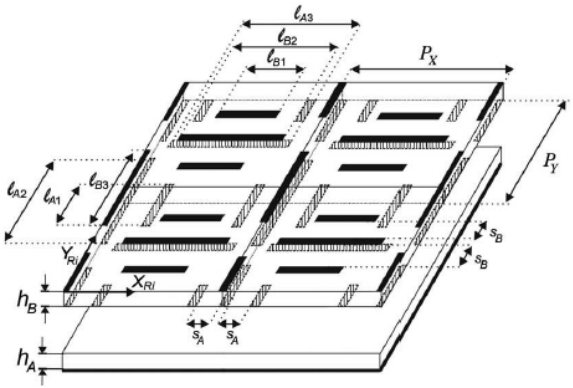
- Higher dipoles will be shorter than lower dipoles, so they will not disturb the phase response of lower dipoles at 19.7 GHz, while lower dipoles will behave as a ground plane at 29.5 GHz.
- The design can be independently run, element by element, for each polarization and frequency:
  - 19.7 GHz: lengths l_{A1} to l_{A3} will control the phase for H-pol., while l_{A4} to l_{A6} will control the phase for V-pol.
  - 29.5 GHz: lengths l_{B1} and l_{B2} will control the phase for H-pol., while l_{B3} and l_{B4} will control the phase for V-pol.

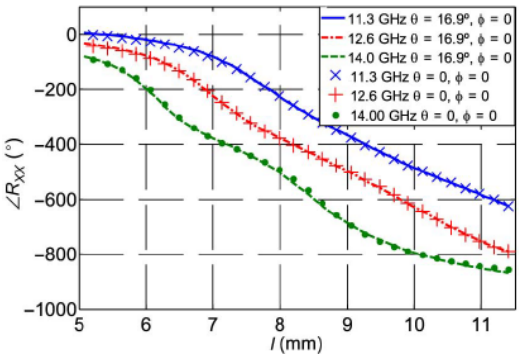


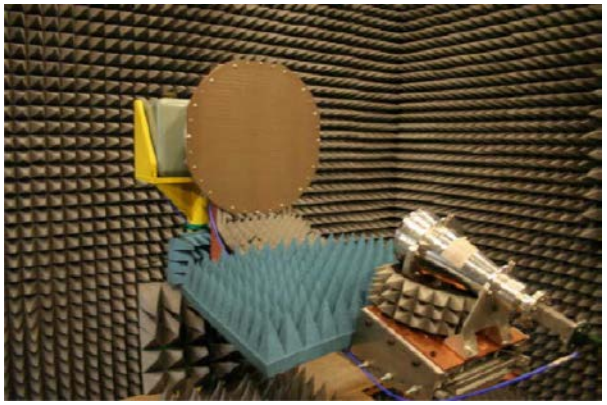


DUAL FREQUENCY DESIGN (II)

- Software analysis routine based on the Method of Moments in the Spectral Domain (SD-MoM) and local periodicity approach.
- Iterative process in which the real angle of incidence on each element is taken into account to obtain the module and phase of the reflection coefficient.
- Fast calculation tool, whose accuracy has been previously validated by manufacturing and measurement of a reflectarray prototype with cells also made of coupled parallel dipoles for each polarization[1].





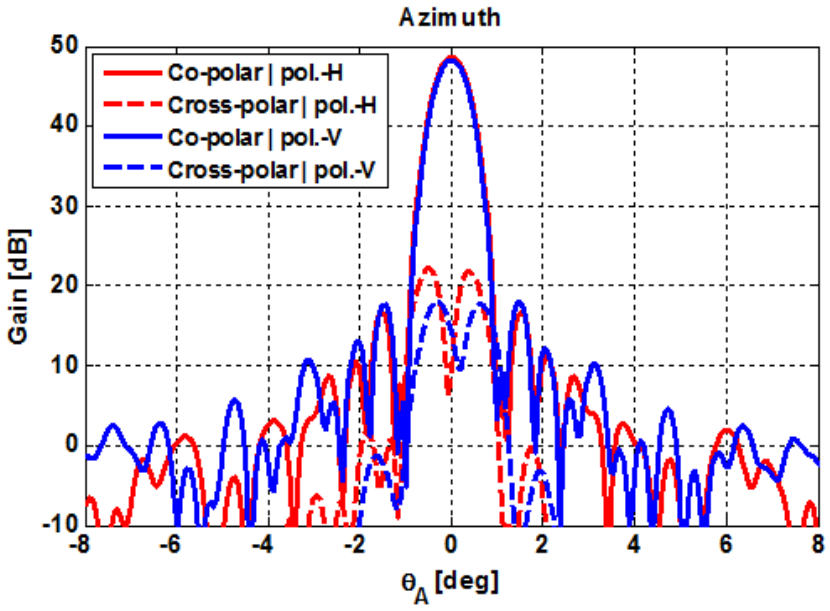


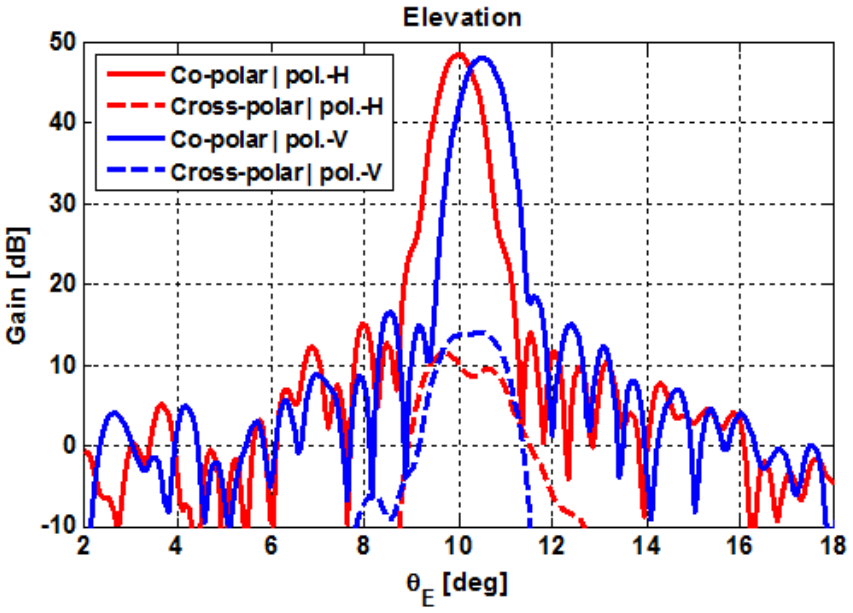
[1] R. Florencio, J. A. Encinar, R. R. Boix, V. Losada, G. Toso, "Reflectarray Antennas for Dual Polarization and Broadband Telecom Satellite Applications," *IEEE Transactions on Antennas and Propagation. Special Issue on Space Antennas*, Vol. 63, pp. 1234-1246, April 2015.

SIMULATION RESULTS (I)

- Radiation patterns at 19.7 GHz for H and V polarizations:
  - Gain: 48.3 dBi.
  - Side-lobe level: -30 dB.
  - Cross-polar level: -27 dB.
  - Beam width: 0.68º.

Radiation efficiency: 66%

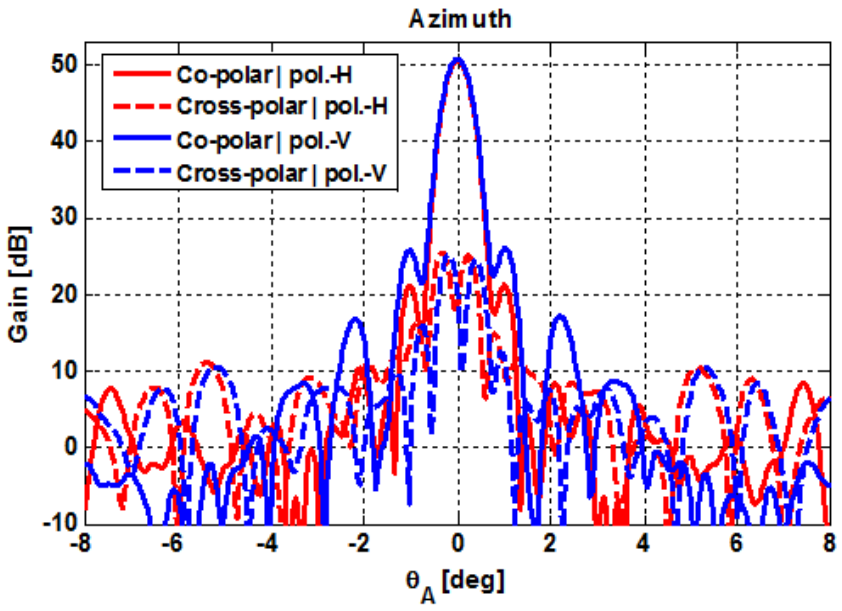


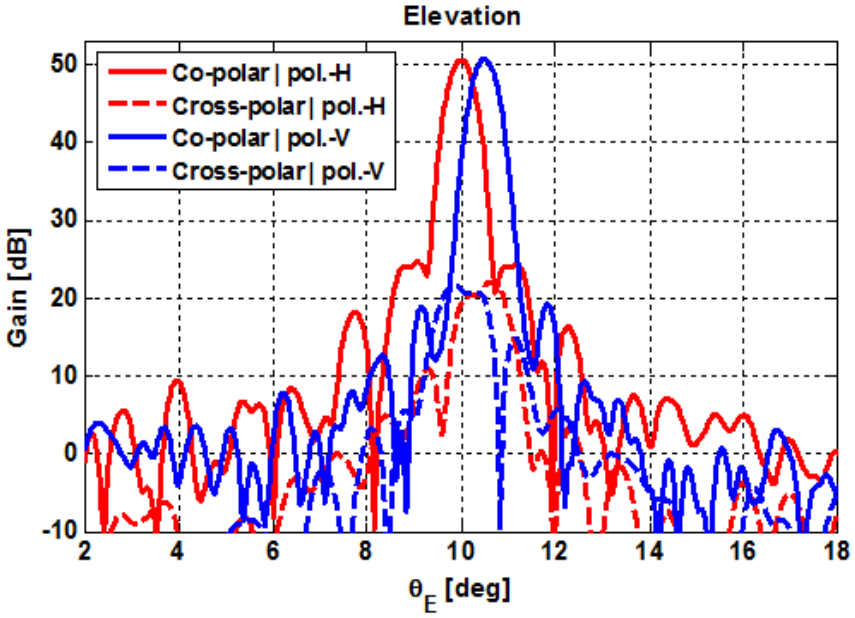


SIMULATION RESULTS (II)

- Radiation patterns at 29.5 GHz for H and V polarizations:
  - Gain: 50.7 dBi.
  - Side-lobe level: -25 dB.
  - Cross-polar level: -25.5 dB.
  - Beam width: 0.55º.

Radiation efficiency: 48%





BANDWIDTH IMPROVEMENT

- The bandwidth centered at 19.7 GHz is around 0.8 GHz with a gain variation less than 1.2 dB, and 0.6 GHz bandwidth is reached at 29.5 GHz with the same gain variation.
- Once the design is completed, a further optimization can be run, in which the dimensions of all dipoles are optimized element-by-element to simultaneously match the phases at the central and extreme frequencies in K and Ka bands[2].
- The optimization can be separately run for horizontal and vertical dipoles, since the phase response is practically uncoupled in the two polarizations H and V.

[2] J. A. Encinar, M. Arrebola, L. F. de la Fuente, and G. Toso, "A transmit–receive reflectarray antenna for direct broadcast satellite applications," *IEEE Transactions on Antennas & Propagation*, vol. 59, no. 9, pp. 3255–3264, Sep. 2011.

CONCLUSIONS

- A 162.5-cm reflectarray antenna has been designed to operate in dual polarization at 19.7 and 29.5 GHz, which are TX/RX frequencies of multi-spot satellite antennas in Ka band.
- The proposed reflectarray element based on orthogonal sets of parallel dipoles provides dual-frequency and dual-polarization operation: independent control of each polarization and frequency.
- The results show the potential of reflectarray technology for multi-frequency operation, as an alternative for space antennas in satellite systems working in Ka band for TX/RX.

ACKNOWLEDGMENT

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